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(19)

(54) IMPROVEMENTS IN OR RELATING TO THE COOLING OF LOW-TEMPERATURE CABLE SYSTEMS

(71) We, LINDE AKTIENGESELLSCHAFT, a German Company of Wiesbaden, Abraham - Lincoln - Strasse 21, German Federal Republic, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

The present invention relates to a method of cooling a low-temperature cable system having three conductors each of which is cooled by a coolant flowing in a respective flow channel, and with three radiation shields each of which surrounds a respective flow channel, coolant being conducted from a plurality of refrigerating units to the cable system and returned therefrom to the refrigerating units.

It is known to provide low-temperature cables with a central flow channel through which flows a coolant, for example, liquid helium. The electrical conductor of the cable is arranged as a plurality of helical strips on the outer surface of this central flow channel. This ensures that the cable has adequate flexibility.

Since the cooled cable must be screened from the prevailing ambient temperature, the sequence of further elements in the cable cross-section proceeding outwardly in the radial direction is: first, the electrical insulation, then an annular vacuum chamber containing super-insulation, an annular channel for the passage of a liquid or gaseous coolant which is referred to as a radiation shield, another annular vacuum chamber containing super-insulation, and, finally, an outer corrosion-protection layer. The spacing required between the individual layers in the cable is provided by support or spacing elements, for example support rings.

The coolant used in the radiation shield may have a temperature of up to a maximum of 120 K, depending upon the design of the cable. The coolant for use in the radiation shield can therefore be in the form of liquid or gaseous nitrogen, or of helium leaving the flow channel of the super-conductive cable. Since hitherto high electric power has been mostly produced as three-phase a.c. and fed in this form into electric power lines, three electrical conductors must be provided in a low-temperature cable system intended for use with three-phase a.c. Known low-temperature cable systems are provided with a plurality of refrigerating units arranged as stations along the long-distance power line. In order to ensure adequate operating reliability of such long-distance lines, they are divided up into individual portions which are themselves independent as far as their refrigeration supply is concerned. This means that the piping for the coolant must be such that each long-distance line portion is fed by a refrigerating unit which is independent of the other refrigerating units. Another difficulty as regards the piping is that the coolant must be fed back from the cable system to the refrigerating unit with the least possible heat loss. For reasons of economy, the flow channels and radiation shields of the cables are conveniently used for this purpose. However, it must be ensured that the required temperature is maintained while this is effected. This presents the further difficulty that the flow channels and radiation shields possess flow resistances which are determined by the particular cable type and coolant used, and consequently an upper limit for the mass flow of the coolant is simultaneously established.

It is an object of the present invention to provide a method for the simultaneous and reliable cooling of a low-temperature cable system having three conductors.

According to the invention, there is provided a method of cooling a low-temperature

cable system having three conductors, each of which is cooled by a single coolant flowing in a respective flow channel, and three radiation shields each surrounding a respective one of said flow channels, said coolant being conducted from a plurality of refrigerating units to the cable system and returned therefrom to the refrigerating units, wherein said flow channels and said radiation shields are divided into a plurality of self-contained sub-systems, each served by an individual refrigeration unit, and wherein in each said sub-system, two streams of coolant are fed to the cable system from the refrigeration unit serving the sub-system, the first of said streams being initially fed to both a first and a second of said flow channels, and the second of which streams is fed to said radiation shields, a part of said first coolant stream leaving said first and second flow channels being fed back through the third flow channel into the refrigerating unit, whilst the remainder of said first coolant stream is united with said second coolant stream.

It is a prerequisite of the present invention that only one coolant, e.g. helium in the liquid and/or the gaseous state, is used, the coolant leaving the refrigerating unit as two coolant streams with temperatures which normally differ, and being fed into a portion of a long-distance line having three electric conductors. These three conductors, for example, super-conductors, can either be each individually located in a respective cable, in which case these three cables are installed together, or else can be located in a single three-wire cable with appropriate spacing elements. Both types of cable system can be cooled equally well by the method of the invention.

The method of the invention has considerable flexibility so far as cooling is concerned, since the cooling of the conductors and radiation shields can be adjusted in accordance with the type of cable involved, by adjustment of the temperature of the two coolant streams leaving the refrigerating unit. Moreover, because only one coolant is used, the two coolant streams can be mixed at each station. It has also been found to be particularly economical that only one of the two streams, namely the first coolant stream, has to be cooled to a very low temperature, since it is only this first stream which provides the actual cooling of the conductors. Only after the first coolant stream has been used to cool the conductors themselves, does a part of this coolant stream and the entire second coolant stream, flow through the radiation shields.

The method of the invention has the further advantage that the volume of coolant in each of the streams used for the cooling of the three conductors can be made equal without any necessity to provide special flow passages for sub-streams of the coolant which serve solely to transport the coolant. In combination with the way in which the radiation shields are cooled in the method in accordance with the invention, this leads to the largest possible intervals between refrigerating units on the cable line, which is of great importance economically.

Having passed through the two flow channels to which it is initially supplied, the first coolant stream is fed onwards in such a way that of its total quantity, one part flows back through the remaining flow channel into the refrigerating unit and another part is united with the second coolant stream for cooling the radiation shields. In a preferred embodiment, these two parts are of equal size, the whole of one half then being passed through the remaining flow channel and the whole of the other half being fed through the radiation shields together with the second coolant stream.

Conveniently, the part of the first stream leaving the second flow channel which is to be united with the second coolant stream may be passed through all three radiation shields up to two points at which these radiation shields are connected to one another. In order to establish these connection points, it is necessary to carry out thermodynamic calculations to determine their optimum siting in the cable system. However, no connection of the flow channels is required, except at the ends of the relevant long-distance line portion, so that it is not necessary to interrupt the electrical insulation of the conductors.

Advantageously, the second coolant stream passes through one of the three radiation shields in the opposite direction of flow to that of the sub-stream of the first coolant stream which enters this radiation shield from the second flow channel and with which it unites at the connection point of the three radiation shields. The basic pattern of the piping ensures that at every point of the cable system the sum of all the mass flows of the coolant which are flowing in one direction is equal to the sum of the mass flows owing in the opposite direction.

Conveniently, the coolant streams entering a connection point of the radiation shields flow from the connection point through a part of the first and second radiation shields back into the refrigerating unit. Thus the coolant cycle for the relevant portion of the long-distance line is closed. This relevant portion is independent of other portions so far as its coolant supply is concerned.

The method of the invention is particularly suitable for the super-conducting cable systems. However, it is also advantageous

for low-temperature cable systems which also operate in the normally conductive range.

The invention will now be further described with reference to the drawing, which is a flow diagram for one embodiment of the invention.

Referring to the drawing, which relates to a super-conductive, three-phase a.c. cable, a first coolant stream composed of very cold helium leaves a refrigerating unit 4 assigned to a specific portion of the cable and flows through a connection line 5 into a second flow channel 2 and a third flow channel 3. On its entry into these flow channels, the temperature of this stream is about 4.5 K at a pressure of 8 bar. The part of the first coolant stream which flows through the second flow channel 2 passes from the end of this portion of the flow channel 2 into a first flow channel 1 and is conducted back into the refrigerating unit 4 via a connection line 11 at a pressure of about 1.5 bar and at a temperature of 6.5 K.

Cross-connections 13 between the second flow channel 22 and the third flow channel 3 enable either a part of the sub-stream fed through the third flow channel 3, to be mixed with the sub-stream flowing through the second flow channel 2, or *vice versa* if so desired, more or less than half of the first coolant stream thus being fed back to the refrigerating unit 4 through the first flow channel 1.

The other part of the first coolant stream which emerges at the end of the third flow channel 3 is fed into three radiation shields 7, 8, 9 at this end of the portion of the cable in question, and flows through these up to two connection points 10. Here the three sub-streams are united with a second coolant stream coming from the refrigerating unit 4 through a connection line 6 and the third radiation shield 9 and which leaves the refrigerating unit 4 at a pressure of 8 bar and a temperature of 60K. The mixing coolant streams flow through the first and second radiation shields 7 and 8 and a connection line 12 back to the refrigerating unit 4.

The individual cooling portions of the long-distance line are all of symmetrical construction in relation to the refrigerating units 4. The designations of first, second, third flow channels and first, second and third radiation shields have been used to facilitate the description. They do not refer to any special properties of the particular flow channels and radiation shields and therefore could be interchanged.

WHAT WE CLAIM IS:—

1. A method of cooling a low-temperature cable system having three conductors, each of which is cooled by a single coolant flowing in a respective flow channel, and three radiation shields each surrounding a respective one of said flow channels, said coolant being conducted from a plurality of refrigerating units to the cable system and returned therefrom to the refrigerating units, wherein said flow channels and said radiation shields are divided into a plurality of self-contained sub-systems, each served by an individual refrigeration unit, and wherein in each said sub-system, two streams of coolant are fed to the cable system from the refrigeration unit serving the sub-system, the first of said streams being initially fed to both a first and a second of said flow channels, and the second of which streams is fed to said radiation shields, a part of said first coolant stream leaving said first and second flow channels being fed back through the third flow channel into refrigerating unit, whilst the remainder of said first coolant stream is united with said second coolant stream.

2. A method as claimed in Claim 1, wherein the whole of the sub-stream of said first coolant stream which is fed to the first flow channel is returned through said third flow channel to said refrigerating unit, and the whole of the sub-stream of said first coolant stream which is initially fed to the said second flow channel is united with said second coolant stream.

3. A method as claimed in Claim 1 or Claim 2, wherein that part of the first coolant stream which on leaving said first and second flow channels is united with said second coolant stream, passes through all three radiation shields as far as two connection points at which said radiation shields are connected to one another.

4. A method as claimed in Claim 3, wherein said second coolant stream passes through one of the three radiation shields in the opposite direction of flow to that of the sub-stream of said first coolant stream which enters this radiation shield and with which it unites at the connection points of the three radiation shields.

5. A method as claimed in Claim 4, wherein said coolant streams entering the connection points of said radiation shields flow back from said connection points through portions of the other two radiation

shields to said refrigerating unit.

6. A method of cooling a low-temperature cable system substantially as hereinbefore described with reference to the drawing.

7. A low-temperature cable system cooled by a method as claimed in any one of Claims 1 to 6.

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1 SHEET *This drawing is a reproduction of the Original on a reduced scale*